A Structured Approach for Treatment of Prolonged Cardiac Arrest Cases in the Coronary Catheterization Laboratory Using Mechanical Chest Compressions

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Abstract

Background: This article aims at describing a logistic approach for prolonged resuscitation efforts in the cath-lab using mechanical chest compressions (MCC) during simultaneous percutaneous coronary intervention (PCI).

Methods: When analysing physiological measurements and logistics in 10 patients experiencing prolonged CA in the coronary intervention laboratory (cath-lab), critical areas for improvement were identified. 1. Understanding and commitment to team work with designated individual roles. 2. Practical simulations within the cath-lab setting. 3. Knowledge of the physiological parameters limitations for successful restoration of spontaneous circulation (ROSC). 4. Familiarity with the advanced technology needed.

Results: The medical emergency team and the cath-lab team were trained as one team. A structured approach was developed: In patients not obtaining ROSC following MCC, a few minutes of advanced life support according to guidelines, perform MCC during simultaneous PCI and optimize physiological parameters: arterial blood pressure >70/40 mmHg, end-tidal carbon dioxide >15 mmHg, 2.0 kPa, pulse oximetry >80%, and cerebral oximetry ~45%. Optimization can be done by repositioning the MCC-device, changing the ventilation rate, by use of vasoactive drugs and correction of acidosis. In shock resistant ventricular fibrillation, maintain circulation by MCC until restoration of coronary flow prior to further defibrillation attempts. Consider therapeutic hypothermia.

Conclusion: Implementing a structured resuscitation approach during prolonged resuscitation efforts in the cath-lab, might improve team work and physiological parameters, which may result in a more calm and success-oriented setting.

Keywords

Resuscitation; CPR; Mechanical chest compressions; PCI; Cardiac arrest

Introduction

Cardiac arrest (CA) in the coronary intervention laboratory (cath-lab) is commonly resolved with defibrillation and a short period of chest compressions (CC). However, in some cases, the patient is in need of prolonged resuscitation efforts and does not obtain return to spontaneous circulation (ROSC) by advanced life support (ALS) according to current guidelines. In a previously study, we have shown a 25% survival rate among patients needing prolonged resuscitation efforts after suffering CA in the cath-lab [1,2]. This was achieved using mechanical chest compressions (MCC) provided by the LUCAS-device (Physio-Control Sweden/Jolife AB, Lund, Sweden) and simultaneously performing emergent percutaneous coronary intervention (PCI). The use of MCC has since been elevated to Class IIa in the AHA guidelines for use during CA in the cath-lab with simultaneous PCI [3].

Through our early experience we identified several points that were complex in this resuscitation situation: Familiarity with the working environment in the cath-lab, team work among the multiple staff involved, recognising the cause of the CA (typically a catastrophic acute closure of a coronary artery), and the opportunity for continuous monitoring of vital physiological parameters during the resuscitation effort. Available physiological parameters in most cath-labs include ECG, arterial blood pressure (ARB), end tidal carbon dioxide (ETCO2) and pulse oximetry (SpO2). These parameters have previously been correlated with successful return of spontaneous circulation (ROSC) in several studies [4-11]. This approach to monitor resuscitation efforts by physiology in cath-lab has to some extent already been described by Kern and co-workers [12], but has not been clinically tested or refined. Furthermore, our cath-lab setting (one interventionist, two registered nurses and one assistant nurse) and the staffing for medical emergencies such as CA (one anaesthesiologist, one registered anaesthetic nurse, one assistant nurse and one cardiologist) differ from day to day, which makes this approach challenging. Since the resuscitation situation is different in the cath-lab compared to a CA in an ordinary hospital ward, the demands for highly regimented team work, with specific assignments for individual personnel are important.

This article aims therefore to describe important changes in the standard advanced life support algorithm when implementing prolonged resuscitation efforts in the cath-lab combining MCC and PCI.

Material and Methods

Mechanical chest compressions were performed using a LUCAS™ device. Parameters of ECG, ABP, central venous pressure (CVP), SpO2 and ETCO2 were monitored on an IntelliVue MP90 monitoring system (Philips, Eindhoven, The Netherlands), and cerebral oximetry (SctO2) was monitored using the FORE-SIGHT (CAS Medical Systems, Inc. Branford, CT, US) monitoring system. Thrombolysis in myocardial infarction (TIMI) flow in non-occluded vessels was assessed as done routinely during PCI [13]. The hemodynamic parameters were recorded every 2nd to 5th ms on an external PC-computer using custom made software and evaluated using Lab Chart 7 (AD Instruments Corp., Colorado Springs, CO,
US). Coronary perfusion pressure (CPP) was calculated as described earlier [13]. Hemodynamic parameters collected are presented as mean ±SD of different time intervals of the MCC period for each patient.

**Deficiencies found in the early experience**

When analysing the physiologic parameters in the first 10 patients with prolonged CA in the cath lab [2] we noticed several deficiencies regarding monitoring and team work. Individual hemodynamic data, treatment and outcome for each patient are shown in Table 1. Four areas needing improvement were identified from this data. First, an understanding of the importance of team work within the unique circumstances of a prolonged resuscitation effort in the cath-lab. Second, the importance of practical simulations within the cath- lab setting. Third, an understanding of the vital physiological parameters for the successful restoration of spontaneous circulation. Fourth, familiarity with the advanced technology needed to succeed during such emergent and stressful circumstances.

**Specific problems addressed following the initial evaluation**

1. The complex collaboration required during resuscitation in the cath-lab between different categories of personnel was not fully appreciated in the beginning. This resulted in suboptimal team work.
2. Only two patients had all physiological parameters collected; we found long periods without recording of ABP data in all patients. In one patient three vital parameters were at suboptimal levels without any corrective action to optimize these parameters (Figure 1). The recommended ventilation rate [14] during resuscitation was not often followed (hyperventilation). We also found numerous variations in artefacts on the recorded ETCO2 curve (Figure 2), ECG-leads and the SpO2 probes fell off frequently and were not always placed on the patient again.
3. The monitor in the cath-lab was optimized for ischemic monitoring (Figure 3a).

4. The resuscitation algorithm was practiced in a separate training area, but not specifically in the cath-lab procedure room, thereby not experiencing the real life space and other limitations in these situations.
5. The extra equipment needed for resuscitation efforts blocked the movement of people in the room as well as the movements of the fluoroscopy equipment.
6. Individual persons in the team were not trained to react in response to the measured physiological parameters, partly due to lack of knowledge of important minimally acceptable levels needed to secure return of spontaneous circulation.

**Results**

**Training and teamwork**

When launching the new approach, several lectures for cardiologists, anaesthesiologists, interventionists, nurses and assistant nurses, were held with focus on training CA-scenarios, team-work and the knowledge of minimally acceptable levels of vital parameters needed for successful resuscitation.

**Monitoring equipment**

In the cath-lab there are two web cameras, these are turned-on at the beginning of any CA situation which gives the possibility to record the resuscitation situation and serve as feedback and debriefing instrument. All hemodynamic measurements important for resuscitation should be recorded on the monitoring equipment in the cath-lab to simplify an instant overview of the vital parameters.

**Other specific recommendations**

- SpO2, ECG and ABP should be measured from the start of all interventions in the cath-lab.
- In case of a CA, defibrillate as early as possible if indicated by rhythm. All these cases are witnessed and do not have a high volume load on the venous side [12,15]. After defibrillation, start immediately CC if the patient does not obtain instantaneous ROSC.

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**Table 1:** Physiologic parameters, CPR time, outcome and drug treatments data in the 10 first patients evaluated, data is presented as Mean ± SD.

<table>
<thead>
<tr>
<th>Patient</th>
<th>ABP Systolic [mmHg]</th>
<th>ABP Diastolic [mmHg]</th>
<th>ABP Mean [mmHg]</th>
<th>CVP Systolic [mmHg]</th>
<th>CVP Diastolic [mmHg]</th>
<th>CVP Mean [mmHg]</th>
<th>SpO2 [%]</th>
<th>ETCO2 [mmHg]</th>
<th>Outcome</th>
<th>CPR time (min)</th>
<th>Nor-epinephrine</th>
<th>Epinephrine</th>
<th>Dobutamin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>114 ± 18</td>
<td>2 ± 12</td>
<td>40 ± 4</td>
<td>123 ± 10</td>
<td>15 ± 11</td>
<td>32 ± 10</td>
<td>82 ± 6</td>
<td>18 ± 2</td>
<td>ROSC (312h)</td>
<td>45</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>2</td>
<td>133 ± 4</td>
<td>10 ± 4</td>
<td>51 ± 3</td>
<td>95 ± 4</td>
<td>-12 ± 3</td>
<td>6 ± 9</td>
<td>81 ± 0</td>
<td>26 ± 2</td>
<td>Dead in lab</td>
<td>50</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>3</td>
<td>63 ± 2</td>
<td>39 ± 3</td>
<td>46 ± 4</td>
<td>95 ± 4</td>
<td>nr</td>
<td>nr</td>
<td>78 ± 4</td>
<td>21 ± 4</td>
<td>ROSC (216h)</td>
<td>75</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>4</td>
<td>50 ± 18</td>
<td>22 ± 8</td>
<td>31 ± 10</td>
<td>10 ± 6</td>
<td>nr</td>
<td>nr</td>
<td>77 ± 6</td>
<td>21 ± 4</td>
<td>Dead in lab</td>
<td>35</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>5</td>
<td>87 ± 7</td>
<td>59 ± 4</td>
<td>68 ± 7</td>
<td>6 ± 9</td>
<td>nr</td>
<td>nr</td>
<td>7 ± 6</td>
<td>46 ± 4</td>
<td>ROSC (13h)</td>
<td>10</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>6</td>
<td>85 ± 6</td>
<td>7 ± 6</td>
<td>33 ± 6</td>
<td>19 ± 1</td>
<td>nr</td>
<td>nr</td>
<td>25 ± 2</td>
<td>64 ± 3</td>
<td>Dead in lab</td>
<td>36</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>7</td>
<td>34 ± 3</td>
<td>20 ± 2</td>
<td>25 ± 2</td>
<td>nr</td>
<td>nr</td>
<td>nr</td>
<td>43 ± 9</td>
<td>23 ± 5</td>
<td>CPC 1</td>
<td>32 ± 8</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>8</td>
<td>139 ± 19</td>
<td>117 ± 15</td>
<td>46 ± 6</td>
<td>19 ± 1</td>
<td>nr</td>
<td>nr</td>
<td>60 ± 16</td>
<td>32 ± 7</td>
<td>Dead in lab</td>
<td>36 ± 3</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>9</td>
<td>81 ± 17</td>
<td>nd</td>
<td>3 ± 6</td>
<td>19 ± 1</td>
<td>nr</td>
<td>nr</td>
<td>36 ± 8</td>
<td>23 ± 5</td>
<td>CPC 1</td>
<td>32 ± 6</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
</tbody>
</table>

**Note:** ABP = Arterial Blood pressure, CVP = Central Venous Pressure, SpO2 = Index finger saturation, ETCO2 = End Tidal carbon Dioxid, nd = not determinet due to artifacts, nr = not registered or lost during procedure. ROSC = Return Of Spontaneous Circulation, CPC = Cerebral Performance Category.
Figure 1: Deficiency in physiological parameters.

Figure 2: Deficiency in physiological parameters.

Figure 3: Monitoring settings. 3a shows the monitoring screen equipment optimized for ischemic monitoring normally used during cardiac interventions. 3b shows the monitoring screen equipment optimized for physiologic monitoring during resuscitation efforts.

If the CA situation has not been solved in a few minutes with manual CC and defibrillations, apply the MCC-device and start CC’s in 30:2 mode (30 CC followed by two ventilations) for patients not intubated. The MCC-device should be placed in the cath-lab for quick access and deployment (Figure 5).

When the patient is intubated, switch to continuous MCCs and a ventilation rate of 10/min, ventilation has to be modified to avoid high intra-thoracic pressures. Intermittent manual ventilation “between compressions” is usually possible. When blood gases are available, ventilation should aim at normoventilation. Blood gases should also be used for adjustment of acidosis if needed.

Alert the medical emergency team whose swift arrival should be in 60-90 seconds.

Select a team leader (most often the cardiologist).

If the patient has a shock resistant VF, continue MCC and precede with PCI in order to open the occlusion, rather than continue with further defibrillation attempts while the culprit coronary vessel remains occluded.

Place the equipment brought by the medical emergency team in dedicated zones marked on the floor, so as not to interfere with the needed fluoroscopic projections; Left anterior...
oblique (LAO) Cranial/Caudal Oblique, RAO Cranial/Caudal Oblique, Straight Caudal, Straight Lateral and Straight Cranial in monoplane (Figure 6).

- As soon as the patient is intubated start monitoring ETCO$_2$.
- To simplify an instant overview of the vital parameters, use a special designed monitor-screen showing one continuous ECG-lead, two ABP-curves, one CVP-curve (optional), one ETCO$_2$-curve, one SpO$_2$-curve and values for SctO$_2$ (Figure 3b).

- Optimize physiological parameters according to Table 2. Since coronary perfusion pressure (CPP) cannot be calculated instantaneously, TIMI might be used as a surrogate marker since it has been shown to correlate to CPP [16,17].
- If systolic ABP is below 70 mmHg, rule out cardiac tamponade, reposition the LUCAS-device (Figure 4), consider change in ventilation rate, or administer inotropic/vasoactive medications. Be careful with the latter to avoid high dose adrenaline (ADR).
- Apply the electrodes of SctO$_2$ on the fore head of the patient as soon as possible if available.
- On the interventionist’s discretion, an introducer in the femoral vein could be inserted, both in order to place a pig tail catheter in the right atria for measuring CVP and to serve as a central venous line for infusions and drug administration.
- Collaboration between the anaesthesiologist and cardiologist is key in all efforts to optimize vital parameters.
- In the relatively rare cases of pulmonary oedema, an adjustable PEEP-valve could be tried. When ROSC has been attained, intermittent positive pressure ventilation using a conventional ICU ventilator can be started.
- Record physiology parameters and communicate to the team leader and anaesthesiologist repeatedly or when dramatic changes occurs, each and every one in the cath-lab has the responsibility to react on unsatisfactory physiology parameters.
- Consider initiation of therapeutic hypothermia as soon as possible.
- If successful PCI is accomplished and the patient has a shockable rhythm, defibrillate during MCC, if no success, consider one bolus injection of ADR (1 mg) followed by defibrillation.
- If successful PCI and the patient has pulseless electrical activity (PEA) or a systole, continue MCC for 15-20 minutes followed by an infusion of ADR for approximately 2-3 minutes, then administering a bolus dose of 1 mg of ADR. Continue MCC for at least 10 minutes after last drug delivery before termination of resuscitation efforts.
- If successful PCI and the patient has obtained ROSC, deploy a left ventricular assist device if needed. Prepare for further post resuscitation treatment in the intensive care unit according to recommendation by guidelines [18] or local directive.

### Table 2: Target values for vital physiological parameters during the resuscitation in the cath-lab setting. Aortic diastolic pressure (AoD), Right atrial diastolic pressure (RaD), Thrombolysis in myocardial infarction (TIMI).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial blood pressure (ABP)</td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>&gt;70 mmHg</td>
</tr>
<tr>
<td>Diastolic</td>
<td>&gt;40 mmHg</td>
</tr>
<tr>
<td>Central venous pressure (CVP)</td>
<td></td>
</tr>
<tr>
<td>Diastolic</td>
<td>&lt;25 mmHg</td>
</tr>
<tr>
<td>Coronary perfusion pressure (CPP)</td>
<td></td>
</tr>
<tr>
<td>(AoD-RaD)</td>
<td>&gt;15 mmHg</td>
</tr>
<tr>
<td>End Tidal Carbon Dioxide (ETCO$_2$)</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>&gt;10 mmHg or &gt;2 kPa</td>
</tr>
<tr>
<td>Pulse oximetry (SpO$_2$)</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>&gt;80 %</td>
</tr>
<tr>
<td>Cerebral oximetry (SctO$_2$)</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>&gt;45 %</td>
</tr>
<tr>
<td>Coronary flow</td>
<td>TIMI-3</td>
</tr>
</tbody>
</table>

**Discussion**

In the cath-lab setting of prolonged resuscitation efforts, it is possible to monitor a number of important physiological parameters that has been predictive of resuscitation success in earlier studies [4-10]. On-going responses during the resuscitation to optimize such parameters might improve outcome, but this could probably only be accomplished when specific roles are assigned in the crucial team work dynamics.
Physiologic parameters

The cath-lab environment offers a unique opportunity to treat prolonged CA since one can immediately react to changes in parameters and evaluate given therapy while the interventionist is attempting revascularisation with PCI. Though the absolute minimal requirements for resuscitation physiological parameters are not known, some reasonable recommendations are possible. Pre-clinical translational studies has suggested a Systolic ABP of at least 70-80 mmHg, a Diastolic ABP $>$ 40 mmHg, a Mean ABP $>$ 40 mmHg \cite{4,9} and other vital parameters as shown in Table 2 are needed to obtain ROSC \cite{5,8,10,11}. The position over the heart of the MCC pressure point might be important to achieve this ABP values \cite{19-21}. If the compression point is inappropriate it can impair circulation, as well as cause injury \cite{21,22}. It is important to assess the quality of ventilation and ventilation rate, since it is well known that hyperventilation has
a negative influence on chest compression generated blood pressure [14]. When analysing ETCO₂ during CCs, be aware that MCC can cause compression artefacts (Figure 2). Providing positive pressure ventilation during MCC can result in barotrauma, hence if possible, experienced personnel should be assigned this task.

Vasoactive drugs

The use of bolus doses of ADR recommended in current guidelines for CPR [23] is not used routinely in our CPR approach for prolonged CA in the cath-lab. Though the general use of ADR during resuscitation efforts remains controversial, it has been shown that high doses of ADR are detrimental [24,25]. In an effort to avoid cumulative high doses of ADR during these prolonged resuscitations using MCC and concurrent PCI, all efforts are made to improve hemodynamic support without repeated dosing with ADR. Noradrenaline (NA) might be a substitute, but it has the same potential for producing “stone heart” in prolonged resuscitations. If the MCC-generated blood pressure is still considered to be insufficient despite changes in placement of the MCC-device, changes in ventilation and rule out cardiac tamponade, we start with an infusion of NA which does not constrict cerebral vessels to the same extent as ADR and provides a higher cerebral oxygen consumption compared to ADR [26]. In an open chest model in cardiopulmonary resuscitation NA improves the O₂-extraction ratio and eases defibrillation in obtaining ROSC compared to ADR [27]. In another study, Brown et al showed significantly higher cerebral blood flow with NA compared to ADR [28]. Thus in our approach we try to preserve acceptable physiology but avoid peak levels with ADR which appear to be harmful.

Treatment perspective

A major difference in this treatment approach proposed for refractory VF in the cath-lab is delaying defibrillation until the culprit coronary artery has been re-perfused. The rationale behind this decision once initial defibrillation proves ineffective is that reperfusion of the myocardium is required for successful restoration of spontaneous circulation. Indeed, the cause of such shock resistant ventricular fibrillation is almost certainly the acutely occluded vessel. Once the vessel is re-opened, defibrillation is usually easily accomplished. Systemic blood pressure and organ perfusion is provided by MCC and followed carefully to ensure adequacy. Our experience has shown that this approach, previously suggested by Kern et al. [12] indeed works. If the patient is in PEA/asystole we continue with PCI during MCC. During the PCI procedure, focus for the non-interventional staff is on optimizing each vital physiological parameter to levels that are predictive of attaining ROSC. When successful reperfusion with PCI is accomplished, additional resuscitation efforts are continued including defibrillation attempts if needed, as well as ADR. We have experienced success in beginning a low dose infusion of ADR to increase ABP 20-40 mmHg or administering a bolus of ADR into the right atria as was done in the early studies [29]. We recommend that resuscitation efforts with MCC, including the use of ADR, continue for at least an additional 20-30 minutes after the termination of the intervention.

Training and team work

An essential part of this modified ALS approach for prolonged CA during PCI is coordinated team work. Due to the large number of different individuals who could be responding with the CA emergency response team, continuous education and practical simulations are performed in the cath-lab with personnel from the CA team as well as from the cath-lab staff. Similar training has been shown to be beneficial in other studies with respect to retain and improve psychomotor skills [30]. The cardiologist and anaesthesiologist have clearly defined roles in the team dynamics. Multiple studies have shown that teamwork and leadership are an important issue in all CPR - performance [31-35]. Studies have shown that deviation from treatment algorithms can result in poorer outcomes [36-38]. This is the reason why the implementation of customized approaches suitable for the cath-lab must be followed with extensive education and practice. Since we have the opportunity to observe all CAS in the cath-lab, all personnel involved in these CA-situations can be debriefed after every case which has been shown beneficial for quality improvement in these critical clinical events [39,40].

Conclusion

When implementing a structured resuscitation approach during prolonged resuscitation efforts in the cath-lab, the improvement in team work and physiological parameters may result in a more calm and success-oriented setting.

Acknowledgement

This evaluation has received grants from Skane Regional Council and Swedish Heart and Lung foundation.

References


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